BEAM DELIVERY SYSTEM DOGLEG DESIGN AND INTEGRATION FOR THE INTERNATIONAL LINEAR COLLIDER

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Abstract

It is proposed to investigate the option of moving the positron source to the end of the main linac as a part of the central integration in the International Linear Collider (ILC) project. The positron source incorporates an undulator at the end of the main linac and the photons generated in the undulator are transported to the target, located at a distance of around 400 m. The dogleg design has been optimised to provide the required transverse offset at the location of the target and to give minimum emittance growth at 500 GeV. The design of the dogleg, the layout changes and the tolerances on beam tuning as a result of locating this dogleg in the beginning of the beam delivery system (BDS) are presented.

INTRODUCTION

The Strawman Baseline 2009 proposal [1] from the ILC Project Management Design Team proposes major changes to the published Reference Design Report (RDR) baseline [2] to address both a reduction in cost and a more complete and robust design approach, taking into consideration the ongoing R&D plans. One of the items for consideration in this proposal is the central integration of several RDR systems in to a central common location. The motivation for this change is the simplification of the central region tunnelling and civil engineering.

The central integration includes the sources in the same tunnel as the BDS. Relocation of the positron production system to the downstream end of the electron linac means placing it just before the beginning of the electron BDS. These changes need suitable design modifications to the layout of this area including modifications to the machine protection and fast abort lines, as well as a dogleg design to provide the required transverse offset for the positron target. In addition to providing the required transverse offset, the emittance growth due to incoherent synchrotron radiation at 500 GeV beam energy (1 TeV centre of mass (CM)) in the design needs to be below a few percent. Similar to the RDR design, the BDS design remains compatible with a 1 TeV CM upgrade which is expected to be accomplished by installing additional dipoles and replacing the final doublet, and thus the dogleg design needs to be designed to deal with emittance growth at all possible beam energies. The new layout satisfying these constraints including the details of the dogleg design and its tolerances are presented here.

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LAYOUT AND DESIGN CONSIDERATIONS

The most notable feature of the new electron BDS layout is the introduction of the dogleg to create the required transverse offset between the electron beamline and the positron photon target. Another important consideration is the protection of the undulator from miss-steering, as well as an electron beam with significant energy errors, and which now shares the same systems foreseen for the BDS. These changes apply only to the electron side.

The RDR has sacrificial collimators in the beginning of the BDS to protect it from any beam with errors entering from the large aperture of the main linac (r = 70 mm) into the small aperture (r = 10 mm) of the BDS. In the new layout, the small aperture undulator (~8 mm full) is located immediately after the linac and thus it needs to be protected against any error beam from the linac. This is achieved by moving the sacrificial collimator section, and an energy chicane to detect the off energy beam, in front of the undulator as shown in Fig. 1. Any beam entering this section with errors will be detected and sent to the fast abort line, before entering, and possibly damaging, the undulator. The fast abort line is presently the same length as the RDR abort line, which was designed as both a fast abort line as well as a tuning line (the positron BDS side still has this combined functionality). However, the fast abort beam dump needs to be able to take only the number of bunches between the abort signal and stopping the beam at the extraction of the damping ring, and does not need to be a full power beam dump.

The matching line to the undulator needs to allow sufficient transverse separation for the abort line and then matching into the undulator FODO cell. The photons generated in the undulator will pass through a drift of 400 m to the positron target. To implement the positron target, and the remote handling of the components in this area, a transverse offset of 1.5 m is required between the electron beamline and the photon target. The remote handing area needs a drift space of approximately 40 m in length where no BDS components are placed. This is achieved by using a matching section after the undulator to match into a dogleg, the dogleg itself giving a transverse offset of 1.5 m with a 40 m long drift section at the end.

The 40 m long drift is followed by a matching section into the skew and coupling correction section, a chicane for detection of laser wire photons and a slow tune-up (DC tuning) line leading to a full power beam dump. Since the fast abort functionality is being taken care of by the fast abort line before the undulator, the energy

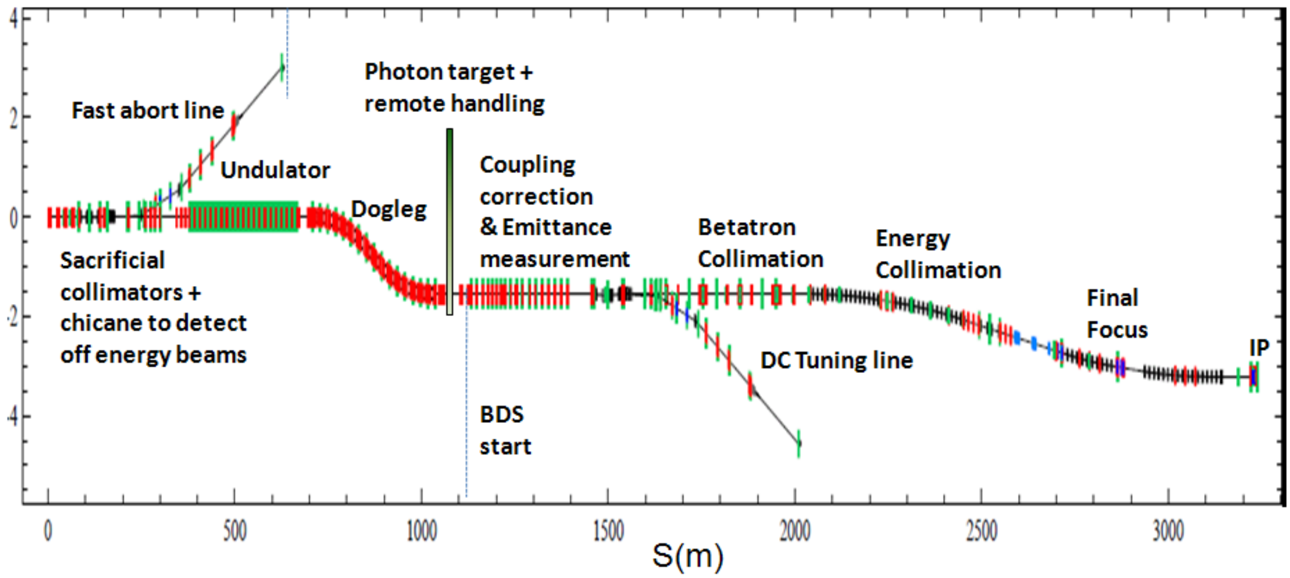

Figure 1: Layout of electron side beam delivery system, IP is the interaction point.

acceptance of the DC tuning line is much reduced and thus the DC tuning line can be shortened using only DC magnets. The polarimeter chicane will be located just after the take-off section for the tuning line, which is not shown in the layout. The betatron and energy collimation, energy spectrometer and final focus sections remain similar to the RDR.

TME DOGLEG DESIGN

The dogleg lattice has been designed as a TME (Theoretical Minimum Emittance) lattice. This keeps the emittance growth due to synchrotron radiation at 1 TeV CM to be within a few percent. The dogleg provides an offset of 1.5 m in 400 m as required and the emittance growth at 1 TeV CM is ~3.8%. The dipoles in the dogleg are presently not decimated as in the rest of the RDR BDS, but can be for better tuning performance at 500 GeV CM. The dogleg lattice design is severely constrained due to the available space of 400 m longitudinally, and with a minimum 1.5 m transverse offset. The requirements on allowable emittance growth constrain the dipole bend angles available to ~1.1 mrad, which in turn lead to constraints on the required focusing through the dipoles. The limited space also constrains the room available for magnets outside of the dipoles. Together, this leads to a very compact, strong focusing lattice. To explore the solution space in terms of quadrupole magnet design, 3 lattice solutions were considered with different maximum pole-tip fields. The three designs all feature 2 quadrupole families per cell, with one central dipole. In the first half of the dogleg, the dipoles bend away (+bend), and in the second half towards (-bend) the BDS. The first and last dipoles in each of the two bending sections have lower bend angles to match the dispersion into, and out of, the dogleg. These dipoles can be used to match and correct incoming errors to minimise the emittance growth seen in the dogleg section.

The three dogleg designs (normalised to 1 m inscribed radius quadrupoles) are detailed in Table 1. These designs represent a trade-off between emittance growth and distance to the positron target. The design utilising 80 Tm quadrupoles has been shown to meet all of the requirements. This design requires 0.8 T pole-tip field for 10 mm maximum inscribed radius, which is achievable. A schematic of the lattice parameters for the 80 Tm design are shown in Fig. 2. Due to the constrained nature of the design, it seems unlikely that many forms of correction hardware can be installed into the lattice, with the possible exception of beam position monitors, and thus incoming trajectory errors must be propagated through the lattice.

Table 1: Dogleg Design Comparison

Element	40Tm Design	60Tm Design	80Tm Design
Bend angle (mrad)	1.1	1.02	1.35
Length (m)	2.0	2.06	7.00
QF Length (m)	5.64	4.83	3.6
QD Length (m)	3.66	3.2	2.6
Smallest Drift Length (m)	0.4	0.4	0.2
Cell length (m)	24.44	20.84	20.6
Number of cells	12	14	12
Number of dipoles	64	72	64
quadrupoles	16	18	16
Emittance growth @1TeV CM (%)	3.67	3.36	3.85
Undulator to target distance (m)	~480	~440	~400

TOLERANCES ON TUNING

Due to the space constraints and strong focusing in the dogleg design, it is expected that the tolerances will be tight. The results of uncorrected mismatch entering the lattice are given in Table 2, for a 10% emittance growth in the lattice at 1TeV CM (cf. 3.8% nominal).

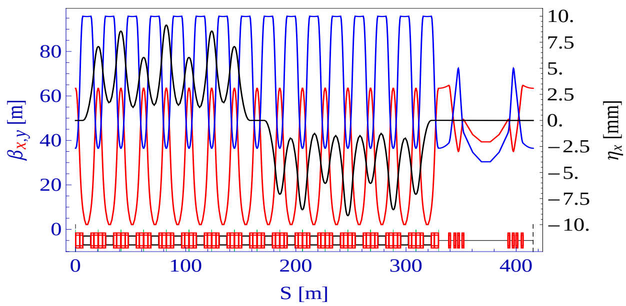

Figure 2: Lattice functions for the 80Tm dogleg design

Table 2: Tolerances for the 80Tm Dogleg Design

Parameter	Tolerance	With Correction
Initial α_x	-1.7 – 1.71	N/A
Initial β_x (m)	10 $\rightarrow$ 200	N/A
Initial η_x (mm)	-9.5 – 11	-21 – 27
Initial η_x' (mrad)	-0.13 – 0.2	-0.32 – 0.4
Initial x (mm) (centroid)	-0.13 – 0.21	-0.6 – 0.75
Initial x' (μrad) (centroid)	-2 – 3.2	-11.5 – 12.9

It is clear that the lattice presents a tight constraint on the allowable incoming dispersion function. As has been noted, this can be partially corrected by using the 4 "end" dipoles (2 +bend, 2 –bend) to correct the incoming, and outgoing, dispersion, whilst also minimising the emittance growth. A further constraint is to minimise the outgoing trajectory error. This trajectory error can also be corrected downstream of the dogleg if required.The improvement, due to correction, on the incoming dispersion tolerances are illustrated in Fig. 3.

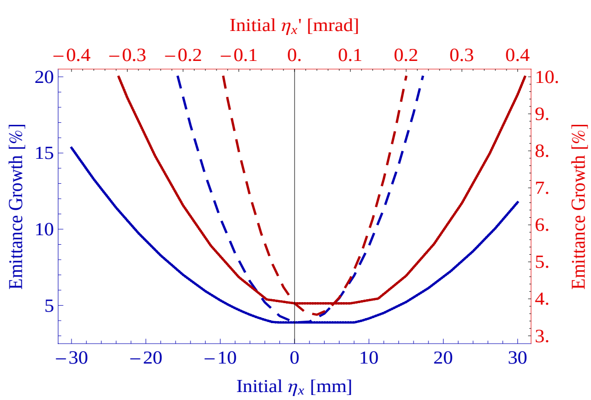

Figure 3: Emittance growth due to incoming dispersion errors, with (solid) and without correction (dashed)

COMPARISON WITH OTHER OPTIONS

The emittance growth due to ISR in the TME design has been compared with two lattices used in earlier designs. The switchyard of TESLA design used a lattice based on double bend achromat and gave a transverse offset of ~0.7 m in ~300 m distance [3]. The 2 mrad big bend lattice used in previous two interaction region configuration for the ILC [4] used combined function dipoles and FODO lattice. This lattice was modified to get a required transverse offset of 1.5 m. The comparison of number of magnets and emittance dilution using these different lattices is given in Table 3.

Table 3: Comparison of Different Lattices for Dogleg

Lattice	Trans. offset (m)	Emit. growth (%) 1TeV CM	No. of magnets	
			Dipoles	Quads
TESLA switchyard	0.7	25	96	16
Big bend like	1.5	19	160	34
TME	1.5	4	20	134

CONCLUSIONS

The changes in the electron side of the beam delivery system are described for the proposed central integration option for the ILC. The TME dogleg design presented here satisfies the layout constraints and gives ~4% emittance growth at 1 TeV CM energy. Due to the strong focussing required in this lattice, the implications on tuning and tolerances have been presented, showing very tight tolerances on the incoming dispersion, as well as the required trajectory correction. Correction of these errors using the 4 "end" dipoles in the design has shown that it is possible to widen the tolerance levels significantly. However, additional correction for the trajectory within the dogleg needs to be looked at further and to understand if decimation of dipoles will be useful to relax the tolerances at 500 GeV CM.

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